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Coupling Enhancement of Waveguide fed Dielectric Resonator Antenna using Tapered Section of Waveguide

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Abstract

A novel technique for coupling enhancement of waveguide fed hemispherical dielectric resonator antenna (DRA) is proposed in this paper. A tapered section of waveguide is inserted between the rectangular waveguide and the ground plane to improve coupling. The tapered section acts as an impedance matching device that increases the coupling from waveguide to DRA. The proposed structure has been simulated using Ansoft HFSS and compared the results with CST Microwave Studio. The effect of various design parameters of the antenna on return loss characteristics is studied.

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Keywords: waveguide;dielectric resonator antenna;tapered section;coupling;capacitive junction.

1. Introduction

In the last three decades, dielectric resonator antenna[1] has been studied extensively because of a number of advantages, such as its small size, light weight, low loss, low cost, and ease of excitation. The absence of conductor loss makes DRA a very good candidate in millimetre wave applications compared to microstrip antennas. Many efficient techniques have been proposed for feeding the DRA, such as coaxial probe[2], direct microstrip[3], aperture coupled microstrip[4], coplanar waveguide[5], and conformal strip[6]. The major disadvantage of these feed types is their considerable losses at millimeter wave frequencies. On the other hand, if waveguide is used for feeding, radiation

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loss and interference effects will not be present. Thus waveguide and DRA acts as an excellent combination for millimeter wave communication systems.

In the literature, very little studies have been reported for rectangular waveguide fed DRAs, either at the waveguide shorted end or at the broad wall. Although a high permittivity DRA can be efficiently excited by an empty waveguide[7], which is not the case with DRAs of low dielectric constants. The inductive reactance offered by the DRA loaded slot gives poor coupling from waveguide to DRA. K. W. Leung and K. K. So have reported an experimental study of waveguide fed cylindrical DRA with a cylindrical dielectric resonator inside the waveguide to increase coupling[8]. But this demands the use of a second DRA to improve the performance. Coupling enhancement of waveguide fed DRA by inserting a capacitive waveguide junction between the waveguide and the ground plane is proposed[9]. However, the very small narrow wall dimension of the capacitive junction makes the fabrication difficult at millimeter wave frequencies. A. B. Kakade *et. al*. used multilayer hemispherical DRA to increase the coupling[10]. However fabrication of multilayer DRA is very difficult.

In this paper a novel technique is proposed to increase the coupling of waveguide fed DRA. The design topology is simple and requires only tapering at the end of the waveguide. The tapered section inserted between the waveguide and the ground plane increases the coupling from waveguide to DRA. The return loss and radiation patterns of the new configuration are studied using Ansoft HFSS and the results are compared with the simulation results obtained using CST microwave studio.

2. Configuration

2.1. Direct coupled waveguide fed DRA

The X Band rectangular waveguide is short circuited by a thick ground plane and a rectangular slot with length, sl and width, sw is cut at the centre of the ground plane for exciting the hemispherical DRA. Fig. 1 shows the three dimensional view and longitudinal cross section of direct coupled waveguide fed DRA. The structure has been simulated using Ansoft HFSS with DRA of dielectric constant, $\varepsilon_r = 10$ and radius, $a_{dr} = 6.27$ mm. The resonant frequency of the DRA used is 10.39 GHz. The direct coupled waveguide fed DRA gives only poor matching as shown in Fig. 2(a). The impedance plot of the structure for a frequency range from 10 GHz to 11 GHz is shown in Fig. 2(b). From the impedance plot it is clear that the poor performance of direct coupling is due to the inductive reactance offered by the DRA loaded slot at resonant frequency. Performance could be improved, if the inductive reactance is neutralised by its capacitive counterpart. To provide the capacitive reactance, a tapered section is introduced between the waveguide and the ground plane.

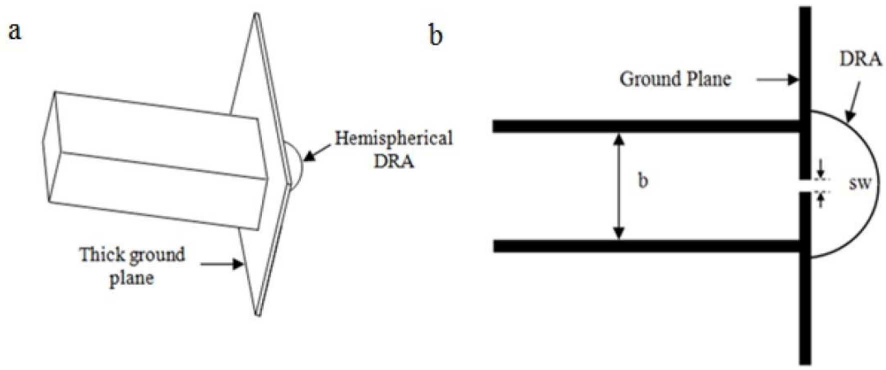

Fig.1. Configuration of direct coupled waveguide fed DRA (a) 3D view; (b) longitudinal cross section.

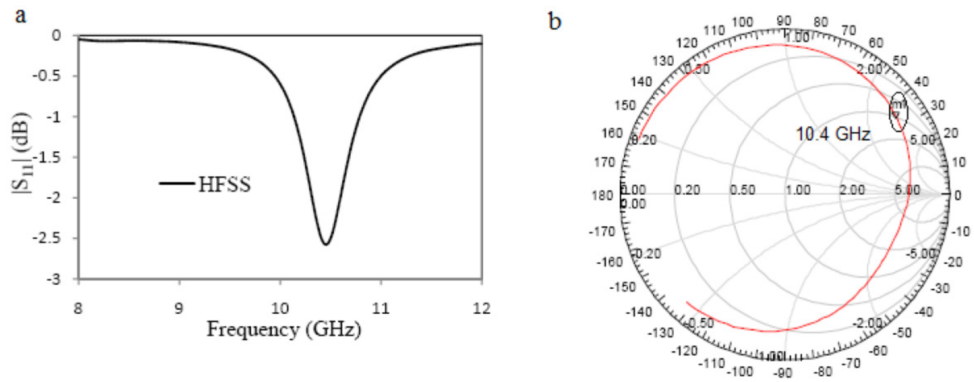

Fig. 2. Simulated results of direct coupled waveguide fed DRA with ground plane 100 mm x 100 mm x 1.3 mm, slot 8 mm x 0.8 mm (a) return loss plot; (b) impedance plot.

2.2. Tapered section coupled waveguide fed DRA

In direct coupled waveguide fed DRA, the waveguide is abruptly terminated by the ground plane. The abrupt termination results in impedance mismatch due to the introduction of inductive reactance. The impedance matching can be achieved by reducing the dimension of waveguide gradually. The dimension of the narrow wall is reduced to provide the required capacitive reactance[11]. The gradual reduction in the narrow wall dimension can be considered as the introduction of a tapered section, between the waveguide and the ground plane as shown in Fig. 3.

The proposed structure consists of a rectangular waveguide of length, L followed by a tapered waveguide of length, tl and angle of tapering, θ. The tapered waveguide is terminated by a square ground plane of thickness, t on which a rectangular coupling slot of dimension, sl x sw is cut. The hemispherical DRA is placed above the slot and at the centre of the ground plane. The longitudinal cross section of the proposed structure is shown in Fig. 3(b).

3. Parametric study and discussion

The commercial software Ansoft HFSS, which is based on finite element method, is used for parametric analysis. Hemispherical DRA of radius, a_{dr} = 6.27 mm with dielectric constant, ε_r = 10 is used in simulations. The waveguide used is WR 90 with cross sectional dimension 22.86 mm x 10.16 mm. The dimension of the thick ground plane is 100 mm x 100 mm x 1.3 mm, on which a slot is cut at the centre. Many design parameters are involved in this problem.

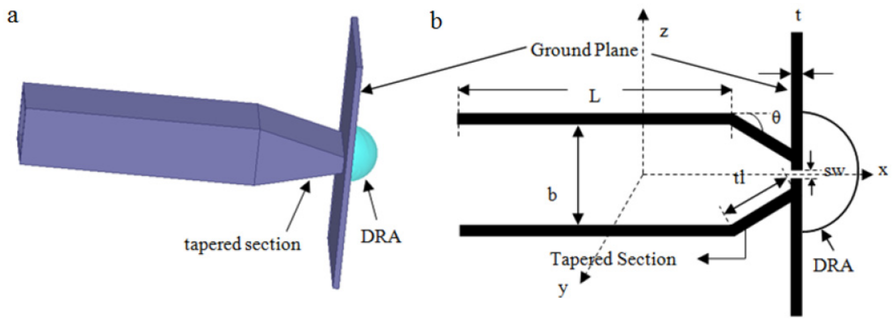

Fig. 3.Structure of tapered section coupled waveguide fed DRA (a) simulation model; (b) longitudinal cross section

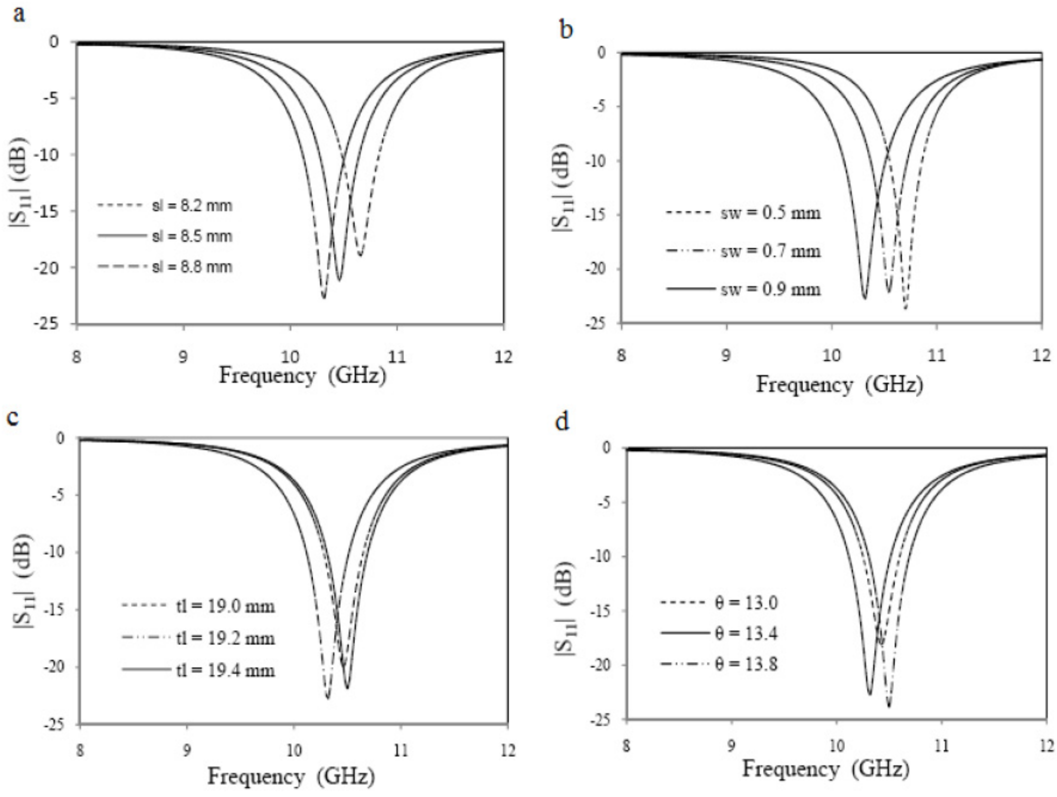

Fig. 4. Simulated return loss as a function of (a) slot length, sl; (b) slot width, sw; (c) length of tapering, tl; (d) angle of tapering, θ.

As the effective permittivity seen by the slot is not exactly known, the resonant length is not well defined. Since the slot is placed on a thick ground plane, its thickness will also influence the resonant frequency and return loss in addition to the length and width. Other parameters, which affect the performance, are the length of tapering and angle of tapering. The design parameters can be optimised to achieve the desired resonant frequency and maximum coupling.

Tuning the DRA to the desired resonant frequency is achieved mainly by adjusting the length of the slot. Fig. 4(a) shows the return loss characteristics when the slot length is varied from 8.2 mm to 8.8 mm in steps of 0.3 mm. Other parameters, the length of tapering (tl = 19.2 mm), angle of tapering (θ = 13.4°), and slot width (sw = 0.9 mm) are kept constant. Increase in slot length causes the resonant frequency to decrease. The resonant frequency close to the DRA resonance is obtained by using the slot length, sl = 8.8 mm. The resonant frequency can also be tuned by adjusting the slot width. The narrow slot is used to avoid cross polarisation. In Fig. 4(b), the variation in return loss is shown as the slot width, sw is varied from 0.5 mm to 0.9 mm, keeping all other parameters constant. The slot width is inversely proportional to the resonant frequency. The slot of width, sw = 0.9 mm gives the resonance close to the DRA resonance, 10.39 GHz.

The parameters of the tapered section determine the narrow wall dimension of the tapered section at the end, which is terminated by the ground plane. Length of tapering will change the resonant frequency and matching. Fig. 4(c) shows the return loss characteristics as the length of tapering is varied from 19.0 mm to 19.4 mm in steps of 0.2 mm. The resonant frequency close to the DRA resonant frequency is obtained for the length of tapering, tl = 19.2 mm. Return loss can be minimised by increasing the angle of tapering as shown in Fig. 4(d). But increasing the angle of tapering will decrease the narrow wall dimension of tapered waveguide. Therefore, the angle of tapering cannot be increased too much. Angle of tapering also influences the resonant frequency. The resonant frequency close to the DRA resonance is obtained for θ = 13.4°.

4. Results

The optimum value for the various parameters obtained by conducting the parametric study is: sl = 8.8 mm, sw = 0.9 mm, tl = 19.2 mm, θ = 13.4°. The return loss plot of the optimised structure is shown in Fig. 5(a). Excellent agreement is obtained between the two simulations. The resonant frequency obtained using simulation is 10.32 GHz, close to the resonant frequency of the DRA. The 10-dB impedance bandwidth is 3.3%. By using the tapered section more than 90% coupling is obtained. The tapered section introduces a capacitive reactance, which makes the reactance at resonance close to zero value as indicated in Fig. 5(b). Fig. 5(c) shows the antenna gain simulated using CST microwave studio. A high gain of 5 dBi is obtained at resonance, with a 3-dB gain bandwidth of 8%. The radiation pattern in both xz plane and yz plane at resonance is shown in Fig. 6(a) and Fig. 6(b) respectively. The co-polarised fields are 40 dB stronger than the cross-polarised fields in the direction of maximum radiation in xz plane at resonant frequency.

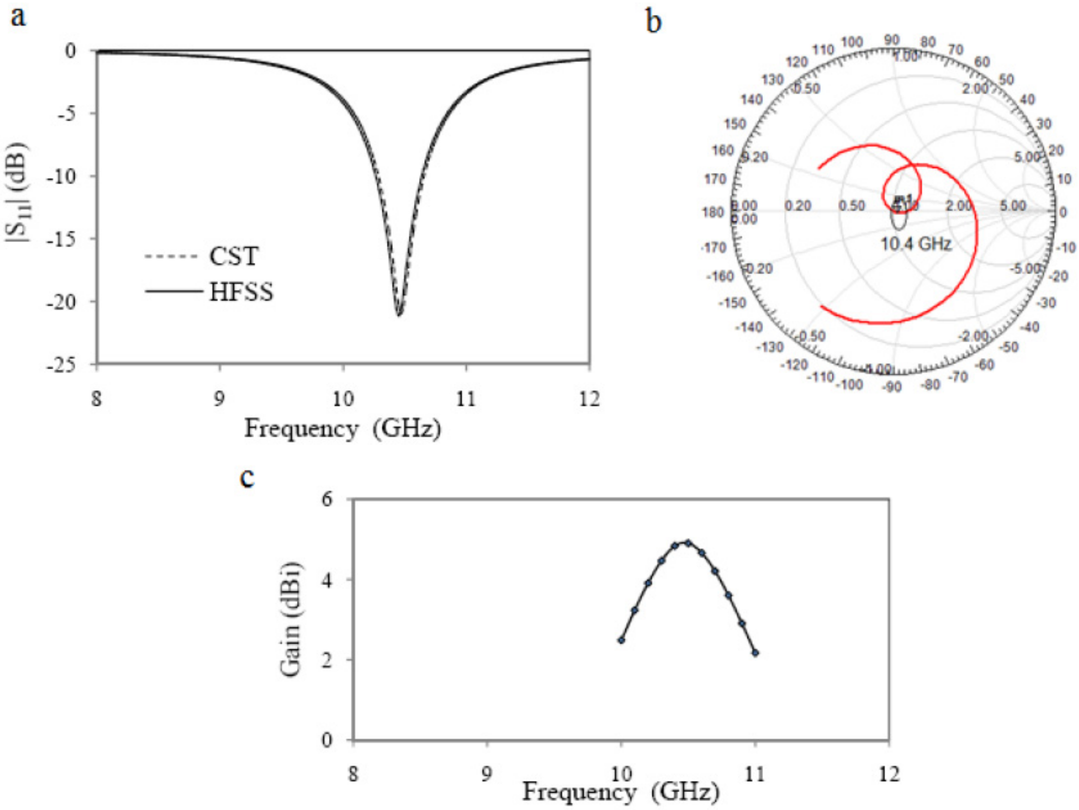

Fig. 5. Simulated results of tapered section coupled waveguide fed DRA with tl = 19.2 mm, θ = 13.4°, sl = 8.8 mm, sw= 0.9 mm (a) return loss; (b) impedance plot from 10 GHz to 11 GHz; (c) gain of the antenna.

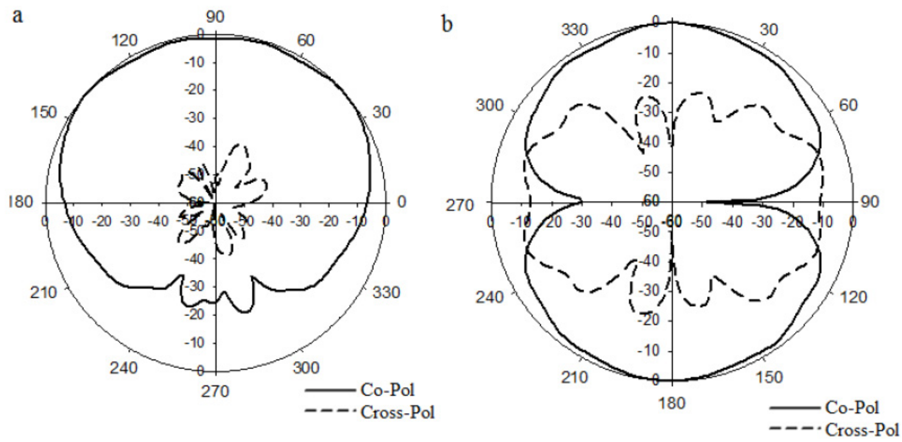

Fig. 6. Simulated radiation pattern of the tapered section coupled waveguide fed DRA with tl = 19.2 mm, θ = 13.4°, sl = 8.8 mm, sw = 0.9 mm at 10.32 GHz (a) in xz plane; (b) yz plane.

5. Conclusion

A method for improving the coupling of waveguide shorted end slot excited hemispherical DRA by inserting a tapered section of waveguide between the rectangular waveguide and ground plane has been studied. The tapered section acts as an impedance transformer which guarantees more than 90% coupling. As both the waveguide and DRA are of very low loss, waveguide fed DRA is a good candidate for millimetre wave applications. The coupling enhancement technique proposed in this paper can be extended for DRAs of other shapes like cylindrical, rectangular etc.

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